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(54) **DIRECTED ENERGY DELIVERY SYSTEMS CAPABLE OF DISRUPTING AIR-BASED PREDATORY THREATS**

(71) Applicant: **Raytheon Company**, Waltham, MA (US)

(72) Inventors: **Michael J. Holihan**, Santa Clarita, CA (US); **Michael C. Prescott**, Redondo Beach, CA (US); **David D. Crouch**, Eastvale, CA (US); **David R. Sar**, Corona, CA (US); **Thomas L. Obert**, Tucson, AZ (US)

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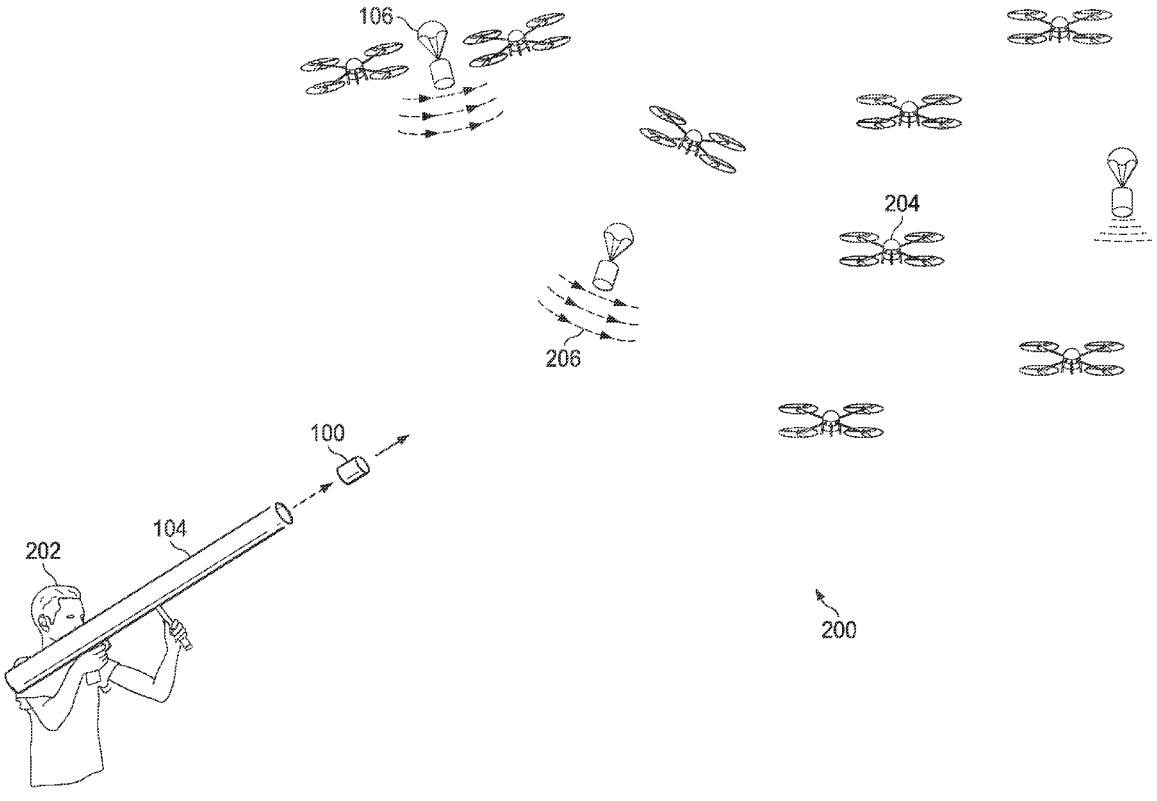
(57) **ABSTRACT**

An apparatus includes a capsule configured to be launched or carried towards an unmanned aerial vehicle (UAV). The apparatus also includes a directed energy device within or carried by the capsule. The directed energy device includes a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV. The capsule can be configured to be launched towards the UAV and can include a loiter mechanism (such as a rotor, umbrella, or parachute) configured to maintain a position of the capsule or to slow a descent of the capsule after launch. The capsule can also be configured to be carried towards the UAV by a different UAV, and the apparatus can further include a tether coupling the capsule to the different UAV.



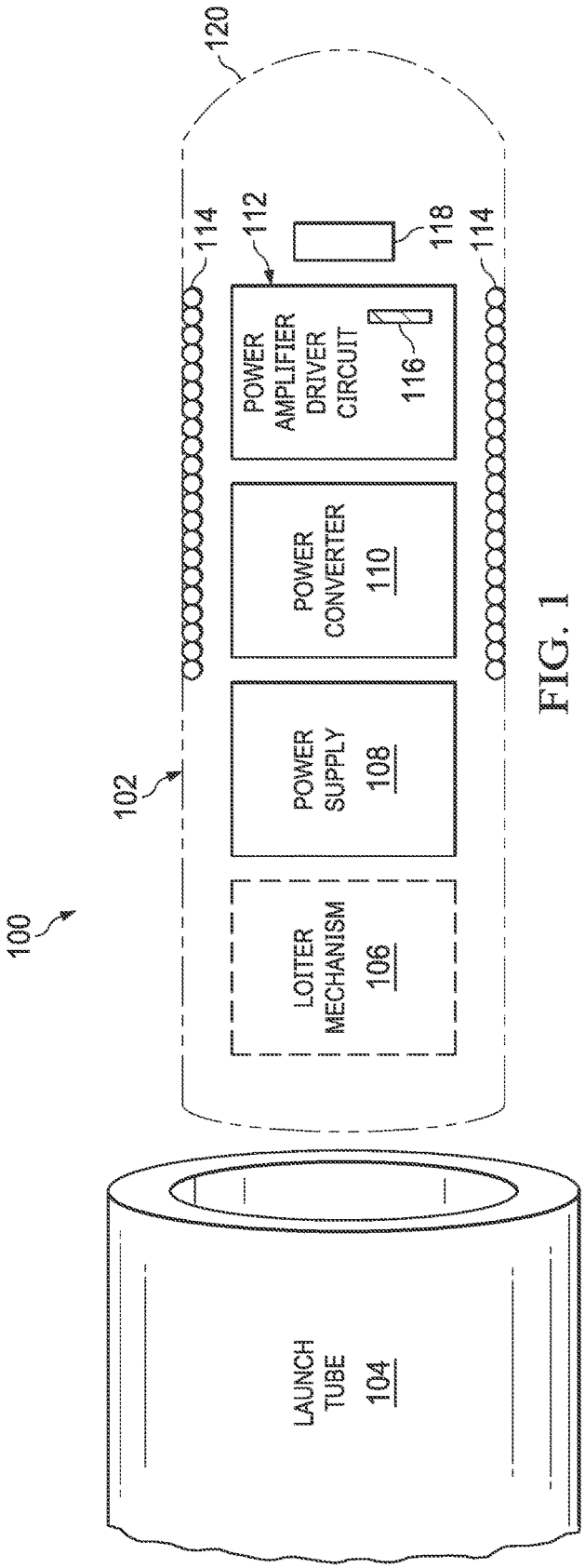

100
102
120
114
112
118
114
POWER AMPLIFIER DRIVER CIRCUIT
116
POWER CONVERTER
110
POWER SUPPLY
108
LOITER MECHANISM
106
LAUNCH TUBE
104

FIG. 1

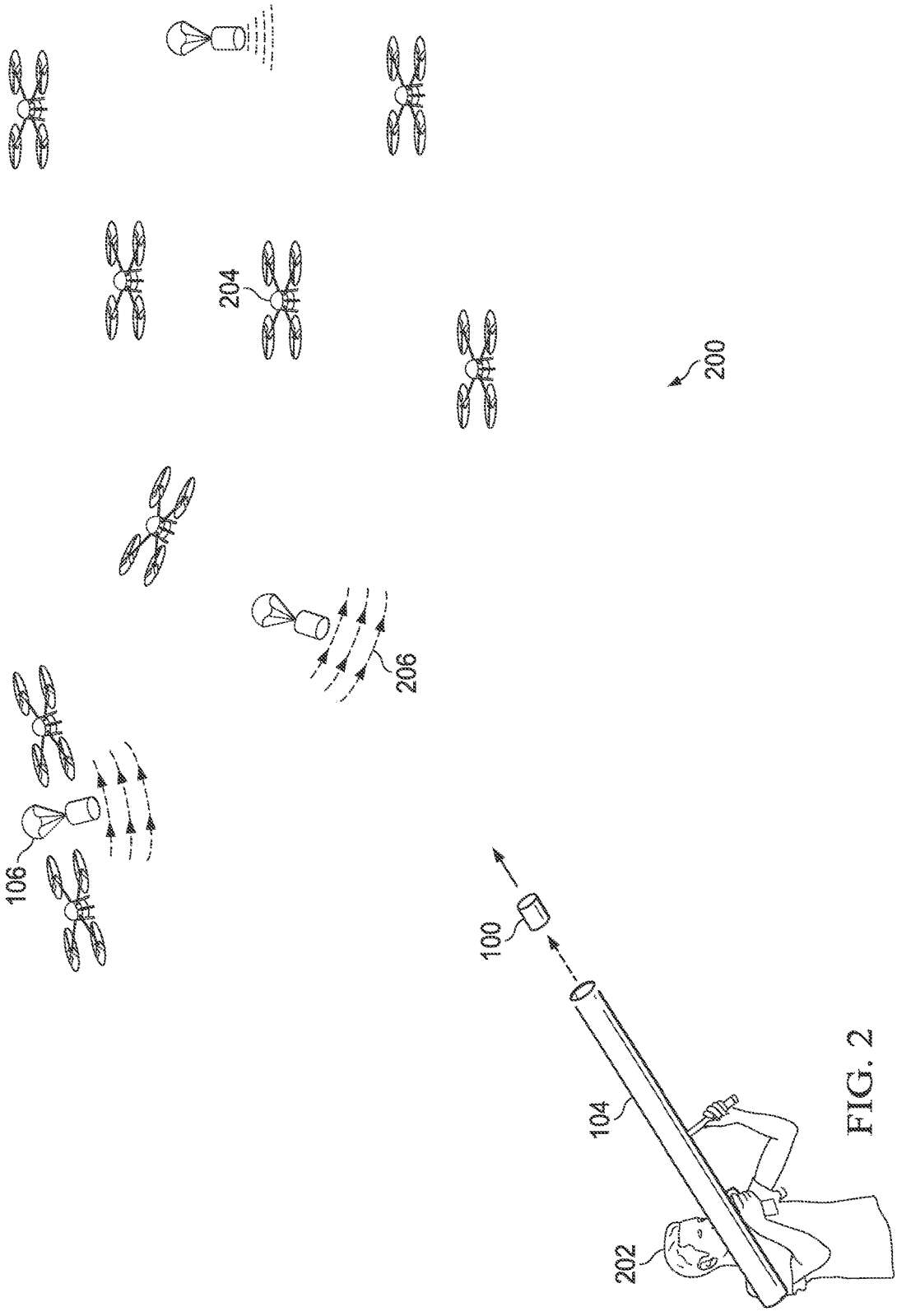


FIG. 2

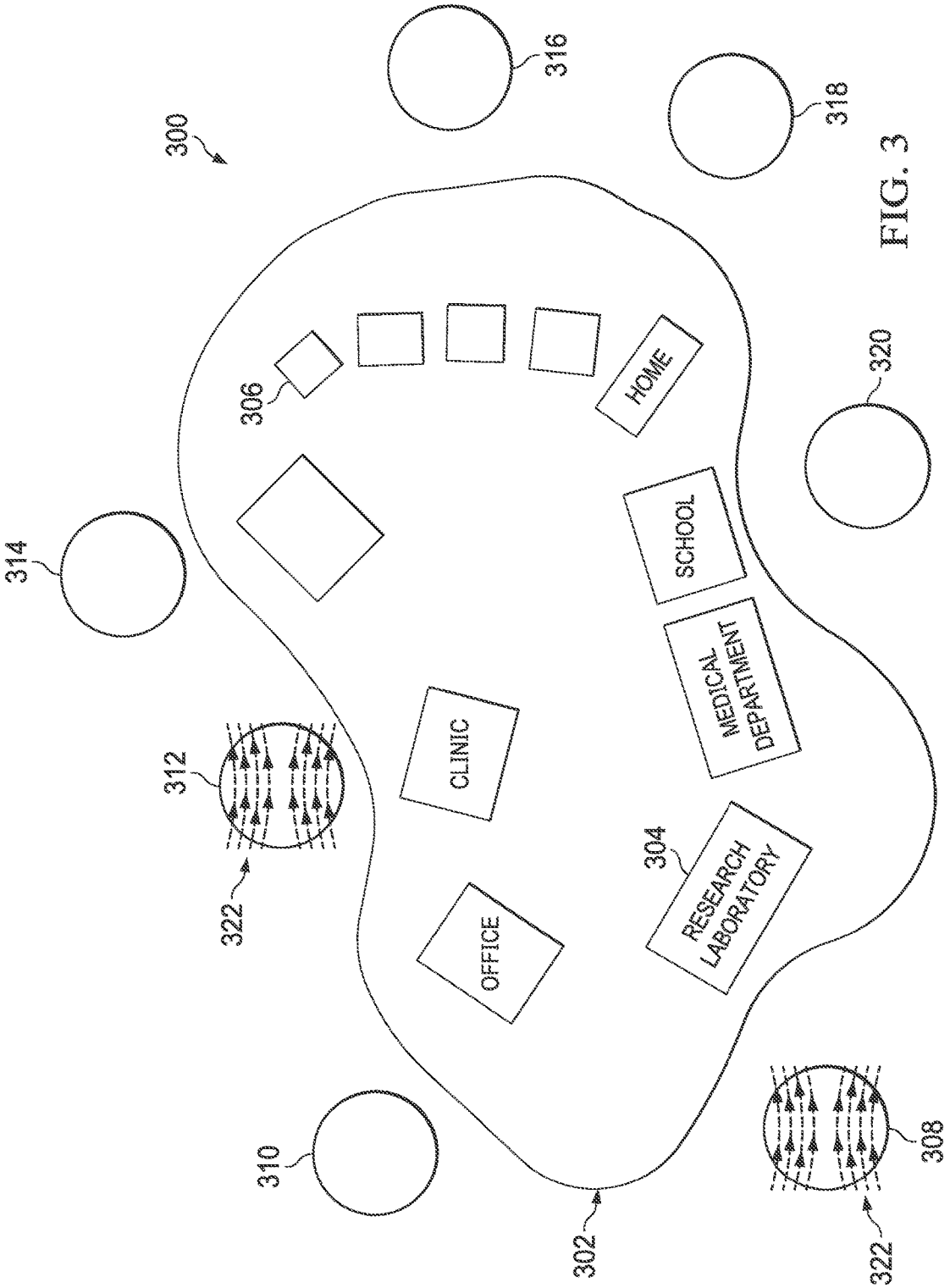
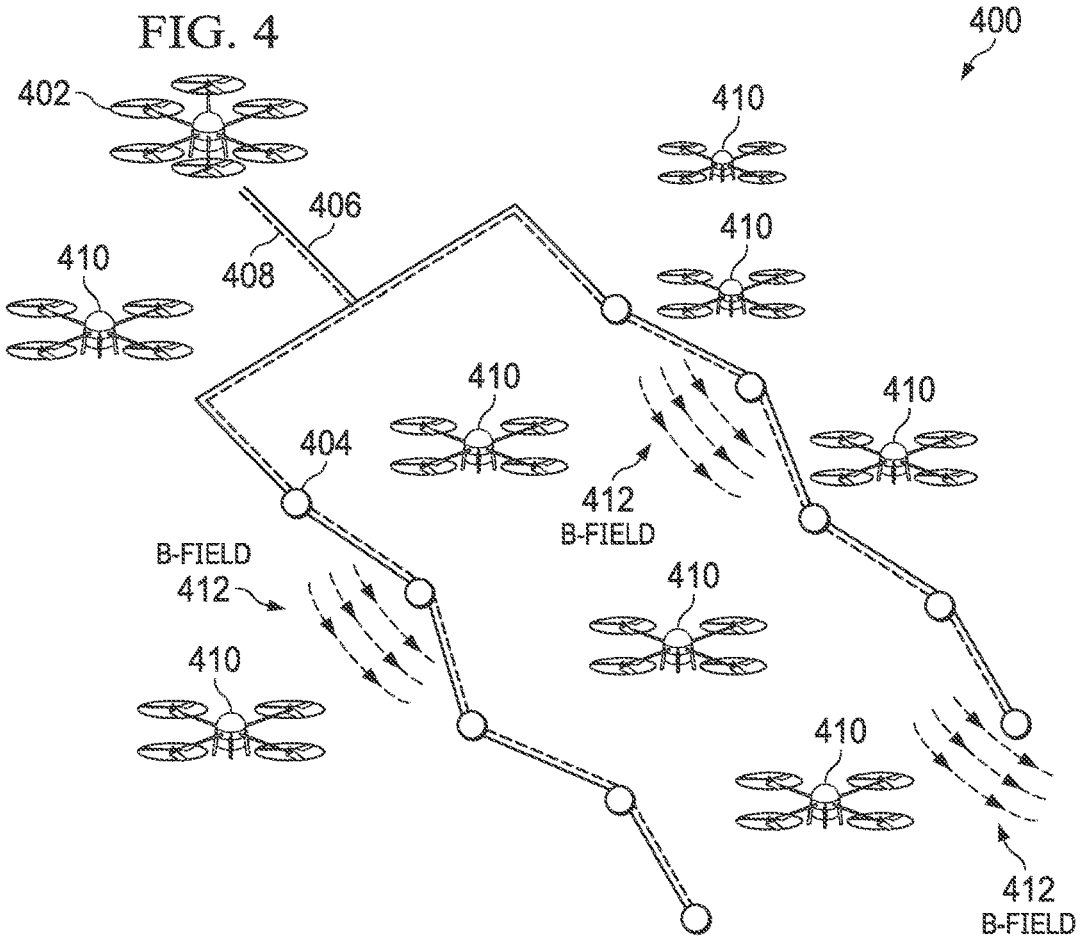

300
316
318
320
314
306
HOME
SCHOOL
MEDICAL DEPARTMENT
CLINIC
312
322
304
RESEARCH LABORATORY
OFFICE
310
302
308
322

FIG. 3

FIG. 4


400
402
410
406
408
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410
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404
412
B-FIELD
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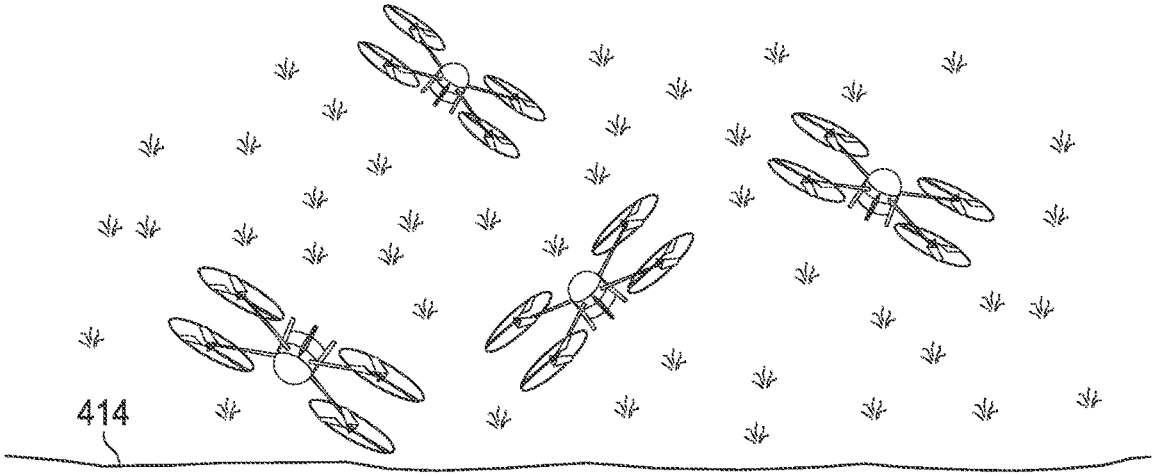
412
B-FIELD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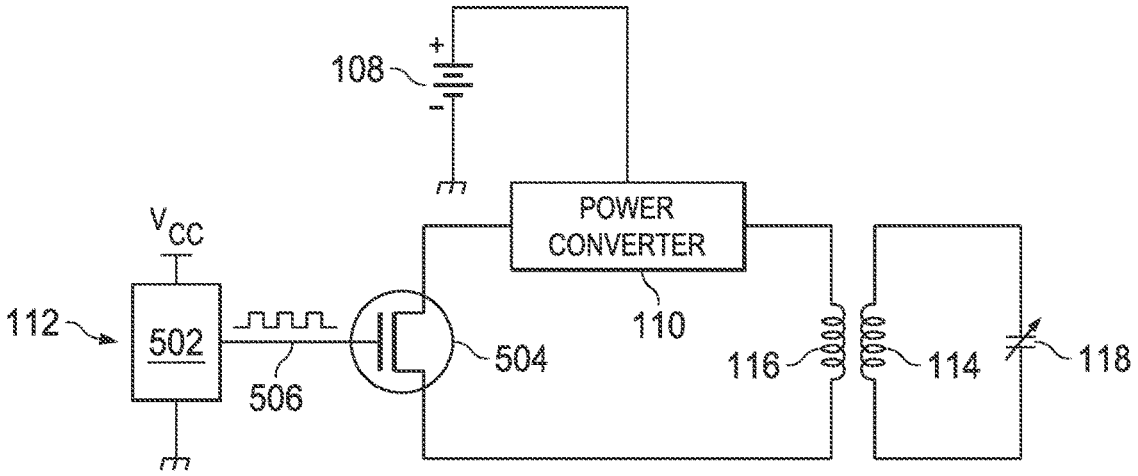

FIG. 5

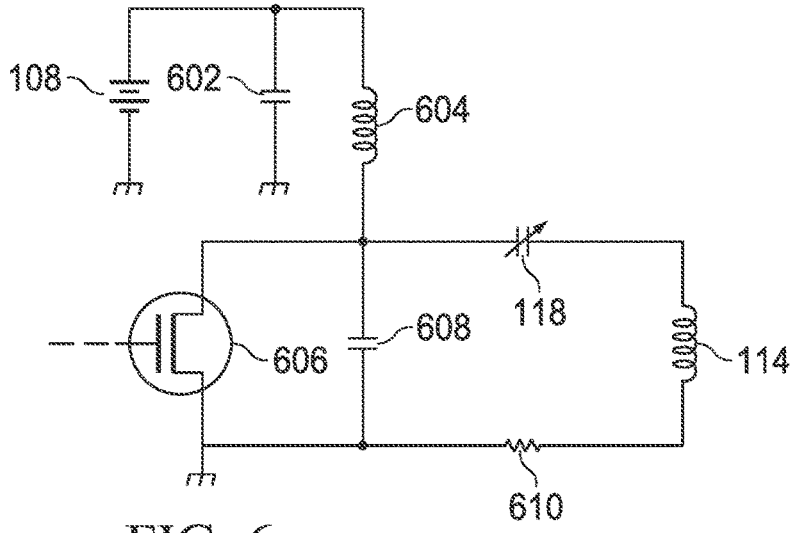

FIG. 6

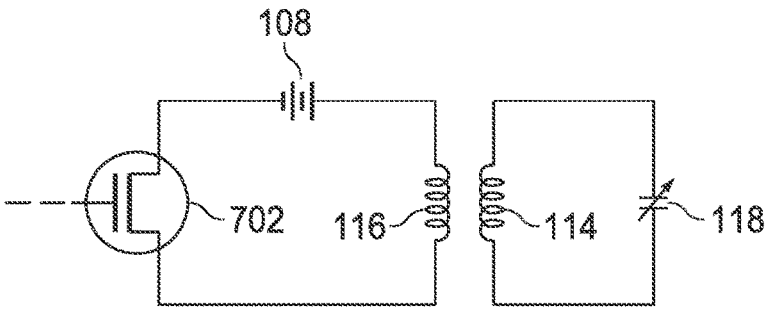

FIG. 7

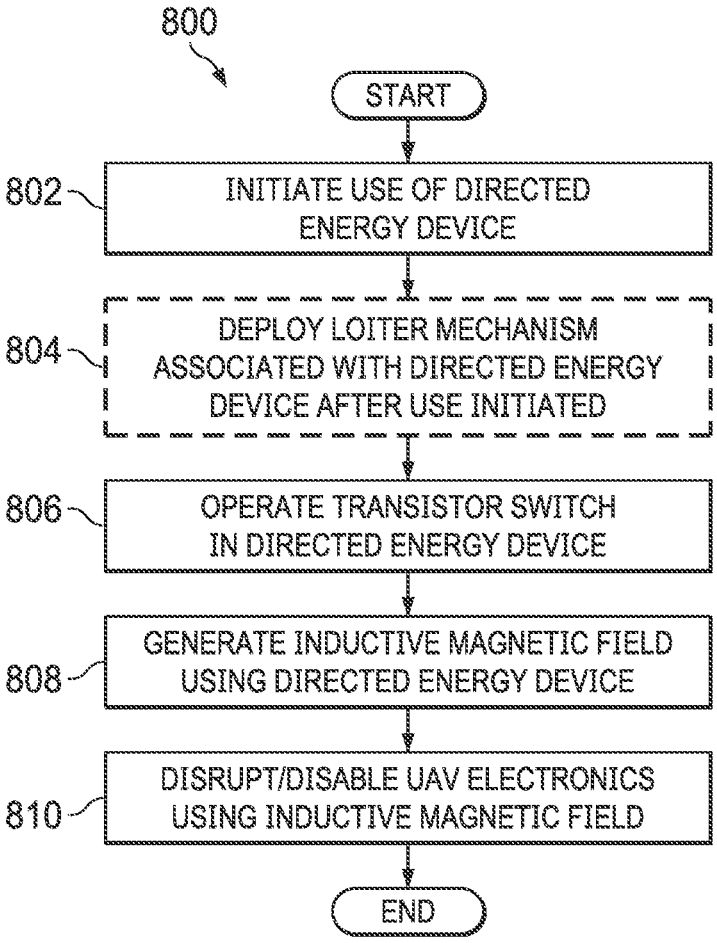
800
START
802
INITIATE USE OF DIRECTED ENERGY DEVICE
804
DEPLOY LOITER MECHANISM ASSOCIATED WITH DIRECTED ENERGY DEVICE AFTER USE INITIATED
806
OPERATE TRANSISTOR SWITCH IN DIRECTED ENERGY DEVICE
808
GENERATE INDUCTIVE MAGNETIC FIELD USING DIRECTED ENERGY DEVICE
810
DISRUPT/DISABLE UAV ELECTRONICS USING INDUCTIVE MAGNETIC FIELD
END

FIG. 8

DIRECTED ENERGY DELIVERY SYSTEMS CAPABLE OF DISRUPTING AIR-BASED PREDATORY THREATS

CROSS-REFERENCE TO RELATED APPLICATION AND PRIORITY CLAIM

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/571,133 filed on Oct. 11, 2017. This provisional application is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure generally relates to protective or defensive systems. More specifically, this disclosure relates to directed energy delivery systems capable of disrupting air-based predatory threats.

BACKGROUND

[0003] Unmanned aerial vehicles (UAVs) come in a variety of shapes and sizes and include devices such as remote-controlled drones, airplanes, and helicopters. While UAVs have been used for a variety of entertainment, commercial, and military purposes, UAVs can be used for more nefarious purposes. For example, various governmental agencies have recognized that UAVs can pose threats to infrastructures such as subways, airports, sport gatherings, soft targets, military sites, power generating sites, and other locations. This is because UAVs provide an easy and inexpensive way for delivering threat payloads, such as radiological agents, plastic explosives or dynamite, nerve agents, or toxic biological agents like anthrax. These types of threats are expected to increase in number as the technical capabilities and commercial availability of UAVs improve. To make matters worse, swarms of UAVs under the control of a single attacker or a group of attackers can exponentially increase the odds of a successful attack against a location.

[0004] Conventional approaches for combatting rogue UAVs fall short in a number of ways. For example, nets can be used to physically capture UAVs, but the nets can be bulky and difficult to deliver at higher altitudes. Radio frequency (RF) jamming devices can be used to interrupt communications with UAVs, but they are often high power, expensive, and stationary and affect the functionality of other nearby electronic devices and systems. Hacking and redirecting UAVs can be effective but can require an undesirable amount of time to occur and can only disable one UAV at a time. Trained eagles have even been used to capture small UAVs that pose public safety hazards, but this approach is not implemented easily on a large scale.

SUMMARY

[0005] This disclosure provides directed energy delivery systems capable of disrupting air-based predatory threats.

[0006] In a first embodiment, an apparatus includes a capsule configured to be launched or carried towards an unmanned aerial vehicle (UAV). The apparatus also includes a directed energy device within or carried by the capsule. The directed energy device includes a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV.

[0007] In a second embodiment, a system includes a plurality of apparatuses each having a capsule configured to be launched towards a UAV and a directed energy device within or carried by the capsule. The directed energy device includes a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV. The system also includes a launcher configured to launch the capsules, where the launcher includes a tube.

[0008] In a third embodiment, a system includes a first UAV and one or more apparatuses each having a capsule configured to be carried by the first UAV towards a second UAV and a directed energy device within or carried by the capsule. The directed energy device includes a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the second UAV in order to disable or destabilize the second UAV.

[0009] In a fourth embodiment, a method includes moving a directed energy device towards a UAV and generating an inductive magnetic field using a first inductor of the directed energy device. The inductive magnetic field is able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV.

[0010] Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a more complete understanding of this disclosure, reference is made to the following description, taken in conjunction with the accompanying drawings, in which:

[0012] FIG. **1** illustrates an example embodiment of a directed energy device capable of disrupting air-based predatory threats in accordance with this disclosure;

[0013] FIG. **2** illustrates a first example environment where a directed energy device capable of disrupting air-based predatory threats can be used in accordance with this disclosure;

[0014] FIG. **3** illustrates a second example environment where a directed energy device capable of disrupting air-based predatory threats can be used in accordance with this disclosure;

[0015] FIG. **4** illustrates a third example environment where a directed energy device capable of disrupting air-based predatory threats can be used in accordance with this disclosure;

[0016] FIGS. **5** through **7** illustrate example embodiments of components within a directed energy device capable of disrupting air-based predatory threats in accordance with this disclosure; and

[0017] FIG. **8** illustrates an example method for disrupting air-based predatory threats using a directed energy device in accordance with this disclosure.

DETAILED DESCRIPTION

[0018] FIGS. **1** through **8**, described below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the present invention may be implemented in any type of suitably arranged device or system.

[0019] As noted above, conventional approaches for combatting rogue unmanned aerial vehicles (UAVs) fall short in various ways. This disclosure provides various approaches for generating and delivering electromagnetic pulses capable of interfering with or disrupting electronics used for control, steering, communication, or other functions of UAVs. For example, in some embodiments, various mechanisms are disclosed for launching one or more relatively small cartridges (also referred to as capsules) each containing a directed energy device into the air and in the flight path of one or more UAVs. The cartridges can be launched in any suitable manner, such as by using a handheld device or a turret-mounted tube. Parachutes or other "loiter" mechanisms can help to hold the cartridges within the flight path of the UAVs.

[0020] Each cartridge includes or is associated with a directed energy device configured to impart an electromagnetic disturbance in the surrounding area, which can have a disruptive or disabling effect on a UAV's steering, velocity, or other essential control aspects. For example, each cartridge can include a "capacitive-discharge" circuit or other circuit that pumps out electromagnetic pulses of interference into a UAV's radio frequency operational spectrum. Typical electromagnetic pulse-generating devices can deliver high current pulses designed to overload RF receiver inputs or other circuits.

[0021] The loiter mechanisms used in some embodiments of the cartridges help to hold the directed energy devices in the air for longer periods of time. This increases the likelihood that the electromagnetic disturbances created by the directed energy devices will successfully disrupt or disable any target UAVs. Any suitable loiter mechanisms can be used, such as parachutes, rotors, or umbrella-like attachments. The loiter mechanisms can simply slow the descent of the cartridges, or the loiter mechanisms can actively attempt to hold the cartridges in the air. One cost-effective benefit of these approaches is that they need not include conventional electro-optical or infrared pointing or targeting techniques to direct the cartridges after launch.

[0022] During use, a field operator or other user can deploy the cartridges ahead of and above the flight path of an intruding UAV, which can help to impart maximal electromagnetic disturbance to the UAV. Deploying the cartridges as close as possible to potential targets helps to overcome significant losses that are inherent with ground-based transmission approaches (since loss is inverse to distance squared). In addition, as a general guideline, it is less expensive to produce a series of relatively low-power transmitters (the directed energy devices) than to fabricate a single transmitter with the same combined power output. These factors indicate that a significant cost-performance benefit may be obtained using the described approaches.

[0023] In some embodiments, the launch mechanism used for one or more cartridges can be self-contained and can resemble a large-diameter shotgun, with a manual or automatic feed mechanism for the cartridges. In particular embodiments, the launcher may use carbon dioxide or nitrogen gas for delivering the cartridges. In other embodiments, the launch mechanism used for one or more cartridges can represent a shoulder launcher. Of course, any other suitable mechanisms can be used to launch the cartridges, such as other handheld or portable launchers or turret-mounted tubes or other devices attached to fixed or movable structures.

[0024] Note that in other embodiments, cartridges with directed energy devices can be carried by a hardened UAV and maneuvered to intercept rogue UAVs, or directed energy devices can be fixed on the ground (possibly in multiple locations around one or more protected areas). In those embodiments, the loiter mechanisms can be omitted, and launching of cartridges containing directed energy devices may not be needed. In general, one or more directed energy devices can be used in any suitable manner to attempt to disrupt or disable one or more UAVs.

[0025] FIG. **1** illustrates an example embodiment of a directed energy device **100** capable of disrupting air-based predatory threats in accordance with this disclosure. More specifically, FIG. **1** illustrates an example internal component layout of the directed energy device **100**. As shown in FIG. **1**, the directed energy device **100** includes or resides within a capsule **102**, which can fit within and be launched from a launch tube **104**. The capsule **102** generally operates to contain other components of the directed energy device **100**, including those components used to disrupt or disable one or more UAVs. The capsule **102** can be formed from any suitable material(s), such as metal or plastic. The capsule **102** can also be formed in any suitable manner. In addition, the capsule **102** can have any suitable size, shape, and dimensions.

[0026] An exit portion of the launch tube **104** is shown in FIG. **1**. The launch tube **104** can be formed from any suitable material(s), such as metal or plastic. The launch tube **104** can also be formed in any suitable manner. Further, the launch tube **104** can represent a stand-alone launcher used to launch one or more directed energy devices **100**, such as a shoulder launcher, large-diameter shotgun, or other handheld or portable device. The launch tube **104** can also represent part of a larger structure, such as a tube mounted on a turret that can rotate and elevate the launch tube **104** to aim the tube. Moreover, any suitable mechanism can be used to launch a directed energy device **100** from the launch tube **104**, such as compressed air (like carbon dioxide or nitrogen gas) or propellant combustion. In addition, the launch tube **104** can have any suitable size, shape, and dimensions.

[0027] In this example, the directed energy device **100** includes a loiter mechanism **106**. After launch, the loiter mechanism **106** can be deployed or otherwise used to increase the loiter time of the directed energy device **100** in the air. For example, in some embodiments, the loiter mechanism **106** represents a parachute or umbrella-like attachment that is deployed after launch to slow the descent of the directed energy device **100** towards the ground. In other embodiments, the loiter mechanism **106** represents a propeller-type rotor that is deployed or used after launch to slow the descent of the directed energy device **100** towards the ground or to attempt to maintain the directed energy device **100** in the air for some desired amount of time.

[0028] Other suitable loiter mechanisms **106** can be attached to or positioned within the directed energy device **100**. This loitering allows for an extended time for engagement of a magnetic B-field created by the directed energy device **100** to inductively couple into a UAV's electronics (such as those used by the UAV for communication, navigation, steering, etc.). The loiter mechanism **106** includes any suitable structure configured to slow the descent of a directed energy device or to maintain a position of a directed energy device in the air.

[0029] The directed energy device **100** also includes a power supply **108**. The power supply **108** is used by other components of the directed energy device **100** to generate a magnetic B-field that disrupts or disables any nearby UAVs. The power supply **108** includes any suitable source of electrical power. In some embodiments, the power supply **108** includes one or more batteries configured to provide pulses at high amperage. In particular embodiments, the power supply **108** includes one or more batteries configured to provide 9-18 VDC or other input voltage. Note, however, that any other suitable source of electrical power can be used here, such as one or more supercapacitors or other electrical storage device(s).

[0030] The directed energy device **100** further includes a power converter **110**. The power converter **110** generally operates to receive an input voltage from the power supply **108** and generate a different output voltage. For example, in some embodiments, the power converter **110** can receive a direct current (DC) input voltage and convert the DC input voltage into a DC output voltage having a different form, such as a higher or lower voltage level. As described below, the power converter **110** supplies power so that a high circulating current can develop within part of the directed energy device **100**, and the power converter **110** can be configured to provide an adequately large output voltage. As a particular example, the power converter **110** can receive a 9-18 VDC input voltage from the power supply **108** and generate an output voltage of 400 VDC or more. The power converter **110** includes any suitable structure configured to receive an input voltage and generate a different output voltage, such as a step-up or step-down converter.

[0031] In addition, the directed energy device **100** includes a power amplifier driver circuit **112** and a first inductor (namely an inductive near-field element **114**). In some embodiments, the power amplifier driver circuit **112** drives one or more field effect transistors (FETs) or other transistor switches to create a varying electrical current through a second inductor (namely an inductive coil **116**). The inductive near-field element **114** and a capacitor **118** form a resonant tank circuit. A source current switched at a high frequency and high voltage (such as the output of the power converter **110** as switched by the power amplifier driver circuit **112**) can be mutually inducted into the tank circuit from the inductive coil **116** so that a high circulating current develops in the tank circuit. In other embodiments, the power amplifier driver circuit **112** drives one or more FETs or other transistor switches to create a high circulating current in the tank circuit in other ways (without mutual inductance via an inductive coil **116**). However the high circulating current is created, this leads to the generation of a magnetic B-field that can be used to engage any nearby UAV's electronics.

[0032] The power amplifier driver circuit **112** includes any suitable structure configured to drive one or more transistor switches, such as a Class E FET driver circuit. The inductive near-field element **114** represents any suitable inductive structure configured to generate a magnetic B-field that can be used to engage at least one UAV's electronics, such as a conductive coil wound within an interior of the capsule **102**. The inductive near-field element **114** can have any suitable inductance, such as an inductance of approximately 7 μH. The inductive coil **116** represents any suitable inductive structure used to mutually induct or otherwise create a variable current flow through an inductive near-field element, such as a smaller coil (compared to the inductive near-field element) located within or coupled to a power amplifier driver circuit. The inductive coil **116** can have any suitable inductance, such as an inductance of approximately 0.15 pH to approximately 0.5 pH.

[0033] The capacitor **118** represents any suitable capacitive structure used to form a tank circuit with an inductive near-field element and can have any suitable capacitance. Since the capacitor **118** is used in a tank circuit designed to resonate, the tank circuit has repeated voltage peaks and current peaks, and the capacitor **118** can have a high breakdown voltage and a very low equivalent series resistance (ESR) in order to reduce or minimize losses due to current flow. Example types of capacitors that can be used here include capacitors formed from mica or Teflon or capacitors that use air or a vacuum. In particular embodiments, the capacitor **118** can be variable or adjustable in order to allow adjustments to the resonant frequency of the tank circuit so that the resonant frequency of the tank circuit matches the drive frequency at which the power amplifier driver circuit **112** drives the one or more transistor switches. This can also be done to adjust size of the space in which the directed energy device **100** can effectively disrupt or disable one or more UAVs. Note, however, that the use of an adjustable capacitor **118** is not required, and other mechanisms can be used to match the resonant frequency of the tank circuit and the drive frequency of the power amplifier driver circuit **112**. For instance, the drive frequency of the power amplifier driver circuit **112** can be adjusted electronically to match the resonant frequency of the tank circuit.

[0034] In this example, the capsule **102** of the directed energy device **100** includes a rounded nose **120** to help reduce air resistance throughout launch and travel. Of course, the nose of the capsule **102** can have any other suitable shape, such as a more pointed nose. Also, as discussed above, the directed energy device **100** can be used in various ways, such as in a shoulder launcher, a large-diameter shotgun, or a turret launcher. The size and shape of the directed energy device **100** can vary depending on how the directed energy device **100** is used. In particular embodiments, the directed energy device **100** is approximately 3.0 inches in diameter and approximately 6.0 inches in length with a rounded nose **120**. Of course, other embodiments of the directed energy device **100** can also be used.

[0035] Through its unique design and operation, the directed energy device **100** helps to provide protection against rogue drones or other UAVs by enabling the disruption or disabling of the electronics used in the UAV(s). As a result, the directed energy device **100** can be used to help protect against threats to subways, airports, sport gatherings, soft targets, military sites, power generating sites, and other locations. Also, directed energy devices **100** can help to provide protection against a single UAV or a swarm of UAVs, and directed energy devices **100** can be small enough to be deployed on multiple platforms around or in a given area. Further, the directed energy devices **100** can generally represent low-cost items and can often be reused, providing a low-cost solution to UAV protection. In addition, the directed energy devices **100** provide a disruptive or disabling effect on UAVs in a non-explosive manner (which can be important when disabling UAVs carrying explosives, incendiary devices, or biological, chemical, or radiological agents) as well as in a non-radiating manner (which can help to limit damage to nearby equipment).

[0036] Directed energy devices **100** can find use in a number of scenarios. For example, directed energy devices **100** can be strategically placed around public events, such as around sports stadiums or other large venues. As another example, directed energy devices **100** can be positioned around "exclusion zones" containing military bases, nuclear reactors or other power generating sites, or other important or sensitive areas. The directed energy devices **100** can even be useful in applications used to counter mines or improvised explosive devices (IEDs) having electronics that can be disrupted or disabled by the directed energy devices **100**. This provides a unique and attractive technique to thwart terrorist threats or other threats to civilian and military targets.

[0037] Although FIG. **1** illustrates one example embodiment of a directed energy device **100** capable of disrupting air-based predatory threats, various changes may be made to FIG. **1**. For example, the directed energy device **100** can be used in any suitable environments to combat any desired UAVs or other targets. Also, electrical systems or components of the directed energy device **100** can be implemented in a number of ways, including (but not limited to) those discussed below. In addition, a number of other features can be used to facilitate aiming and launch of the directed energy device **100**. For instance, a laser range finder can be provided on the launch mechanism (such as on the launch tube **104**) to identify an estimated range to a rogue UAV or other target. As another example, a blinking light emitting diode (such as a green LED) can be provided on a directed energy device **100** to provide line-of-sight feedback enhancement, such as for nighttime usage. As a third example, a directed energy device **100** can include an embedded glue trap or other structure on the outside of the capsule **102** that facilitates physical attachment to a UAV or other target in the event that the directed energy device **100** actually strikes the UAV or other target.

[0038] FIG. **2** illustrates a first example environment **200** where a directed energy device capable of disrupting air-based predatory threats can be used in accordance with this disclosure. As shown in FIG. **2**, a user **202** can launch one or more directed energy devices **100** using the launch tube **104**. Each directed energy device **100** can be directed towards a drone **204** or other UAV or towards a swarm of drones **204** or other UAVs. It may be necessary or desirable to launch multiple directed energy devices **100** towards the drone **204** or swarm of drones **204**. As noted above, each directed energy device **100** can be gas-propelled or propelled in any other suitable manner.

[0039] One or more directed energy devices **100** ideally get within close proximity of each predator drone **204** in order to disrupt or disable the drone **204**. For example, launching a directed energy device **100** both ahead of and above a predator drone **204** (at the apex of the flight path of the directed energy device **100**) can strongly increase the likelihood of disrupting or disabling the drone **204**. The loiter mechanism **106** used with each directed energy device **100** increases the loiter time of that directed energy device **100** in the air. This loitering allows for an extended time for engagement of a B-field **206** created by the directed energy device **100** to inductively couple into the predator drone's electronic controls. This can help to disrupt or disable the drone's controls used for communication, navigation, steering, or other functions.

[0040] In particular embodiments, directed energy devices **100** can achieve a launch velocity of approximately 150 feet per second and enable an altitude intercept of up to approximately 300 feet, although other launch velocities and altitude intercepts can occur. In some embodiments, velocity adjustments can be made by a field operator or other user **202**, such as by turning a dial or adjusting another control of the launch tube **104** to control the launching of the directed energy devices **100**. In some cases, the launch tube **104** can include a manual or automatic feed mechanism for the directed energy devices **100**, allowing multiple directed energy devices **100** to be launched from the launch tube **104** quickly.

[0041] As can be seen here, the directed energy devices **100** operate by attempting to inductively couple into a drone's electronics to disrupt or disable the drone **204**. Collateral damage can be kept to a minimum due to the non-explosive and non-radiating nature of the directed energy devices **100**, thereby enabling a potential intact recovery of a disabled drone **204**. Also, each directed energy device **100** can fully discharge before reaching the ground so that no unintentional inductive coupling occurs on the ground with other devices or systems. In addition, spent/used directed energy devices **100** can be collected, recharged, and potentially re-used to minimize recurring costs.

[0042] FIG. **3** illustrates a second example environment **300** where a directed energy device capable of disrupting air-based predatory threats can be used in accordance with this disclosure. As shown in FIG. **3**, the environment **300** includes an exclusion perimeter **302**, which generally identifies the boundary of an area to be protected against predator drone or drone swarm attacks. The exclusion perimeter **302** can encompass one or more soft targets **304** or one or more homes **306**. The soft targets **304** in this example include buildings that house offices, clinics, research laboratories, medical facilities, and schools. However, the soft targets **304** can include any other or additional facility or facilities.

[0043] In this example, larger directed energy devices **308-320** act as a stand-alone defense rather than being launched into the air. These stand-alone directed energy devices **308-320** can, for example, sit on tall standoffs or poles, tall buildings, or other tall structures and create magnetic B-fields **322** used to intercept one or more drones or other UAVs in order to disrupt or disable the one or more UAVs. Intercept parameters can be tailored for these types of embodiments. Ideally, the directed energy devices **308-320** prevent entry of any drones or other UAVs past the exclusion perimeter **302**.

[0044] These stand-alone directed energy devices **308-320** can be activated in any suitable manner. For example, the directed energy devices **308-320** can be remotely or automatically activated, such as based on a perimeter section that may be breached by one or more drones or other UAVs (which can be detected by radar or other detection systems). The directed energy devices **308-320** can also be triggered manually, such as based on manual observation of one or more incoming drones or other UAVs.

[0045] The directed energy devices **308-320** can have the same general form as the directed energy device **100** shown in FIG. **1**, although various modifications can be made to support the use of the directed energy devices **308-320** in the environment **300** (such as by making the directed energy devices **308-320** larger and more powerful). For example,

the capsules **102** of the directed energy devices **308-320** can have a different form factor, such as larger spherical capsules or capsules of other larger shapes. As another example, the directed energy devices **308-320** can have the option of being powered from 110 VAC or other alternating current (AC) power sources, thereby allowing the directed energy devices **308-320** to produce stronger B-field effects during flyovers of drones or other UAVs. This may be needed or desired since the directed energy devices **308-320** here are not launched to be in close proximity to rogue drones or other UAVs. As yet another example, the directed energy devices **308-320** can include mounting brackets or other mounting hardware allowing the directed energy devices **308-320** to be mounted to standoffs, poles, buildings, or other structures.

[0046] FIG. **4** illustrates a third example environment **400** where a directed energy device capable of disrupting air-based predatory threats can be used in accordance with this disclosure. As shown in FIG. **4**, a friendly UAV (referred to as a "workhorse" drone **402**) is used to pull a plurality of directed energy devices **404**. In this example, the workhorse drone **402** pulls ten directed energy devices **404** and the directed energy devices **404** are spherical, although other numbers and shapes of the directed energy devices **404** can be used.

[0047] The workhorse drone **402** can drag the directed energy devices **404** through the environment **400**, such as by using a tether assembly **406**. The tether assembly **406** can incorporate electrical conductors or other structures to provide each directed energy device **404** with electrical power. As a particular example, the tether assembly **406** can include a copper or other conductive wire harness **408** that is fed by the workhorse drone **402**. Alternatively, each of the directed energy devices **404** can include its own power supply as described above. Thus, the directed energy devices **404** can have any of the designs discussed above, or the directed energy devices **404** can have designs similar to those discussed above but modified to support the receipt of operating power from a remote source.

[0048] This embodiment is designed to allow the workhorse drone **402** to maneuver its way through the air space of a swarm of predator drones **410**, making certain that the associated B-field **412** of at least one directed energy device **404** creates a disruptive or disabling inductive effect to the closest predator drone(s) **410**. The desired result is to decommission all predator drones **410** in the swarm to earth ground **414**. In order to prevent the directed energy devices **404** from disrupting or disabling the workhorse drone **402** itself, the workhorse drone **402** can be hardened against magnetic coupling, such as through appropriate shielding of its electrical components.

[0049] The directed energy devices **404** can have the same general form as the directed energy device **100** shown in FIG. **1**, although various modifications can be made to support the use of the directed energy devices **404** in the environment **400**. For example, the capsules **102** of the directed energy devices **404** can have a different form factor, such as a spherical shape. As other examples, the directed energy devices **404** can include mounting hardware allowing the directed energy devices **404** to be mounted or otherwise connected to the tether assembly **406** and optionally electrical contacts allowing the directed energy devices **404** to receive electrical energy through the wire harness **408**.

[0050] Although FIGS. **2** through **4** have illustrated example environments where at least one directed energy device capable of disrupting air-based predatory threats can be used, various changes may be made to FIGS. **2** through **4**. For example, the directed energy devices **100**, **308-320**, **404** can be used in any other suitable environments to combat any suitable threats. Also, while the directed energy devices **100**, **308-320**, **404** are often described above as being used against drones, the directed energy devices **100**, **308-320**, **404** can be used to provide protection against any other UAVs.

[0051] FIGS. **5** through **7** illustrate example embodiments of components within a directed energy device capable of disrupting air-based predatory threats in accordance with this disclosure. In particular, FIGS. **5** through **7** illustrate example embodiments of components shown as residing within the directed energy device **100** of FIG. **1**. However, the same or similar components can be used in the directed energy devices **308-320** of FIG. **3** or the directed energy devices **404** of FIG. **4**.

[0052] FIG. **5** depicts an example embodiment of components in a directed energy device **100**. In this example, an on-board frequency or clock circuit **502** with a variable duty cycle drives a transistor switch **504**. The transistor switch **504** is coupled in series with the power converter **110** and the inductive coil **116**. The circuit **502** is coupled to ground and to receive a supply voltage V_{cc}, and the circuit **502** outputs a drive signal **506** with a variable duty cycle.

[0053] The drive signal **506** is provided to a gate of the transistor switch **504**. The drive signal **506** contains pulses that cause the transistor switch **504** to repeatedly become conductive and non-conductive, thereby creating a variable current through the inductive coil **116**. This variable current causes the inductive coil **116** to create a varying magnetic field that couples into the inductive near-field element **114**. The inductive near-field element **114** and the capacitor **118** form a resonant tank circuit, and the current through the inductive coil **116** is mutually inducted into the tank circuit. This creates a high circulating current in the tank circuit, causing the inductive near-field element **114** to generate a magnetic B-field used to disrupt or disable any nearby UAV's electronics.

[0054] There is typically no shielding of the electronics in a drone or other rogue UAV from the directed energy device's high slew dB/dT near-field generated by the inductive near-field element **114**. The produced inductive magnetic field is designed to result in the disabling or destabilization of the predator drone or other UAV's electronics. This can occur through resetting of the target's microprocessor, resetting of the target's counters, corrupting of control circuit information, etc. While some absorbing materials such as ferrite materials can theoretically be used to provide protection against the produced inductive magnetic field, those materials are heavy and not suitable for use in rogue UAVs. The use of superconductive materials might also conceivably provide protection against the produced inductive magnetic field, but rogue UAVs typically lack superconductive materials, and the ability of superconductive materials to provide protection against the produced inductive magnetic field is not a certainty.

[0055] The most susceptible components of a drone or other UAV may be those with low voltage and current requirements, such as solid-state devices, integrated circuits, semiconductor devices, digital computers, digital circuitry,

alarm systems, and electronic sensors. Generally, as the size of the device decreases, its ability to absorb these current spikes decreases, resulting in an increased susceptibility to the directed energy device's B-field. Creating a rapidly-varying current (such as 50-100 Joules of high dI/dT current) through the inductive near-field element **114** can disrupt or disable a drone or other UAV's electronics by producing a fast rising dB/dT field and subsequent electric field in an incident conductor (the drone or other UAV's electronic components).

[0056] The circuit **502** includes any suitable structure configured to generate a suitable clock signal or other drive signal. The transistor switch **504** includes any suitable structure for selectively forming and breaking an electrical connection, such as a quantum field effect transistor (QFET), other FET, or other transistor. Note that the transistor switch **504** can be capable of handling large voltage levels and voltage spikes, although metal-oxide varistors (MOVs) or other protective circuits can be used to reduce the voltage spikes at the transistor switch **504**. One example of a transistor switch **504** that can potentially be used here is the IXTA02N450HV high-voltage power MOSFET from INYS CORP. In some embodiments, the circuit **502** and the transistor switch **504** form at least part of a Class E amplifier network. Also, the circuit **502** and the transistor switch **504** can operate at any suitable frequencies, such as at a frequency below 1 MHz for launched or pulled directed energy devices **100**, **404** or higher frequencies for larger directed energy devices **308-320**. In particular embodiments, the circuit **502** and the transistor switch **504** can operate in frequencies not exceeding several tens of megahertz. Note that the capacitor **118** in FIG. **5** is shown as being variable or adjustable, although as noted above this is not required.

[0057] FIGS. **6** and **7** illustrate alternative embodiments that can be used in the directed energy device **100** for generating pulses. As shown in FIG. **6**, a capacitor **602** is coupled in parallel with the power supply **108**, and both the power supply **108** and the capacitor **602** are coupled to an inductor **604**. The inductor **604** is also coupled to the capacitor **118**, a transistor switch **606**, and a capacitor **608**. The transistor switch **606** and the capacitor **608** are coupled in parallel with each other, and the capacitor **118** is coupled in series with the inductive near-field element **114** and a resistor **610**. The capacitor **118** and the inductive near-field element **114** here form a series resonant circuit, and the transistor switch **606** can be selectively opened and closed across the capacitor **608** to create a high circulating current in the series resonant circuit. A gate of the transistor switch **606** can be coupled to an on-board frequency or clock circuit (such as the circuit **502** described above) to control the opening and closing of the transistor switch **606**.

[0058] Note that the design of the directed energy device **100** shown in FIG. **6** includes a modified version of a Class E amplifier. In a normal Class E amplifier, the load being powered by the amplifier would be represented by the resistor **610**. In this example, however, the focus is on supplying a variable current to the inductive near-field element **114**. The inductive near-field element **114** is made physically large to extend its B-field outward, unlike in a conventional Class E amplifier. Note that this approach does not rely on mutual inductance of the current through an inductive coil **116** into the inductive near-field element **114**.

[0059] Each capacitor **602** and **608** includes any suitable capacitive structure, such as a standard capacitor or a supercapacitor. Each capacitor **602** and **608** can also have any suitable capacitance. The inductor **604** includes any suitable inductive structure having any suitable inductance. The transistor switch **606** includes any suitable structure for selectively forming and breaking an electrical connection, such as a QFET, other FET, or other transistor. The resistor **610** includes any suitable resistive structure and can have any suitable resistance.

[0060] As shown in FIG. **7**, a transistor switch **702** is coupled in series with the power supply **108** and the inductive coil **116**. The inductive near-field element **114** is coupled in parallel with the capacitor **118**, forming a parallel resonant circuit. The transistor switch **702** can be selectively opened and closed to create a varying current through the inductive coil **116**, and the varying current can be mutually inducted to the parallel resonant circuit. The gate of the transistor switch **702** can be coupled to an on-board frequency or clock circuit (such as the circuit **502** described above) to control the opening and closing of the transistor switch **702**. This approach is similar to that shown in FIG. **5**, but the power converter **110** is omitted. The transistor switch **702** includes any suitable structure for selectively forming and breaking an electrical connection, such as a QFET, other FET, or other transistor.

[0061] As can be seen here, there are various ways in which circuitry can be designed to cause the inductive near-field element **114** to generate a magnetic B-field used to disrupt or disable electronics of any nearby UAVs. In general, any suitable series and/or parallel resonant circuit(s) can be used in the directed energy device **100** to generate a magnetic B-field used to disrupt or disable electronics of one or more UAVs. Further, in particular embodiments, any of these circuits can support inductor coils that are radially distributed around a central tuning capacitor.

[0062] Although FIGS. **5** through **7** illustrate example embodiments of components within a directed energy device capable of disrupting air-based predatory threats, various changes may be made to FIGS. **5** through **7**. For example, while described as being used in the directed energy device **100**, the components shown in FIGS. **5** through **7** can be used in the directed energy devices **308-320** or the directed energy devices **404**. Also, electrical systems or components of the directed energy devices **100**, **308-320**, **404** can be implemented in a number of ways to generate pulses, and the specific implementations described above are examples only.

[0063] FIG. **8** illustrates an example method **800** for disrupting air-based predatory threats using a directed energy device in accordance with this disclosure. For ease of explanation, the method **800** of FIG. **8** is described as being performed using one or more directed energy devices **100**, **308-320**, **404** in the environments **200-400** of FIGS. **2** through **4**. However, the method **800** can involve the use of any suitable directed energy device(s) in any suitable environment.

[0064] As shown in FIG. **8**, use of at least one directed energy device is initiated at step **802**. This can include, for example, a user **202** launching one or more directed energy devices **100** from a launch tube **104**. This can also include activating one or more directed energy devices **308-320**, such as in response to detection of one or more incoming drones or other UAVs. This can further include launching or maneuvering a workhorse drone **402** carrying one or more directed energy devices **404** towards one or more UAVs.

[0065] A loiter mechanism associated with each directed energy device can optionally be deployed after use of the directed energy device is initiated at step **804**. This can include, for example, deploying a parachute, umbrella-like attachment, rotor, or other loiter mechanism **106** from the capsule **102** of each directed energy device **100**. Note, however, that this step is optional if the directed energy device is not launched. For instance, no loiter mechanism may be needed for the directed energy devices **308-320** or for the directed energy devices **404**.

[0066] At least one transistor switch within each directed energy device is operated at step **806**, and an inductive magnetic field is generated using each directed energy device at step **808**. This can include, for example, the power amplifier driver circuit **112** operating a transistor switch **504** or **702** to generate a varying electrical current through the inductive coil **116**, which can be mutually inducted into a resonant tank circuit or otherwise provided from the inductive coil **116** to the tank circuit such that a high circulating current develops in the tank circuit. This can alternatively include the power amplifier driver circuit **112** operating a transistor switch **602** to otherwise generate a high circulating current in a resonant tank circuit. The tank circuit includes the inductive near-field element **114** and the capacitor **118**.

[0067] The inductive magnetic field is used to disrupt or disable at least part of the electronics of one or more drones or other UAVs at step **810**. This can include, for example, the inductive magnetic field from the inductive near-field element **114** inductively coupling into the one or more UAVs' electronics. As particular examples, this can include the inductive magnetic field from the inductive near-field element **114** inductively coupling into the one or more UAVs' electronics in order to reset a UAV's microprocessor, reset one or more of the UAVs' counters, or corrupt the UAV's control circuit information. Ideally, this disrupts or disables the one or more UAVs while causing little if any adverse effects on nearby devices or systems.

[0068] Although FIG. **8** illustrates one example of a method **800** for disrupting air-based predatory threats using a directed energy device, various changes may be made to FIG. **8**. For example, while shown as a series of steps, various steps in FIG. **8** can overlap, occur in parallel, occur in a different order, or occur any number of times.

[0069] In some embodiments, various functions described in this patent document are implemented or supported by a computer program that is formed from computer readable program code and that is embodied in a computer readable medium. The phrase "computer readable program code" includes any type of computer code, including source code, object code, and executable code. The phrase "computer readable medium" includes any type of medium capable of being accessed by a computer, such as read only memory (ROM), random access memory (RAM), a hard disk drive, a compact disc (CD), a digital video disc (DVD), or any other type of memory. A "non-transitory" computer readable medium excludes wired, wireless, optical, or other communication links that transport transitory electrical or other signals. A non-transitory computer readable medium includes media where data can be permanently stored and media where data can be stored and later overwritten, such as a rewritable optical disc or an erasable storage device.

[0070] It may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The terms "application" and "program" refer to one or more computer programs, software components, sets of instructions, procedures, functions, objects, classes, instances, related data, or a portion thereof adapted for implementation in a suitable computer code (including source code, object code, or executable code). The term "communicate," as well as derivatives thereof, encompasses both direct and indirect communication. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrase "associated with," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The phrase "at least one of," when used with a list of items, means that different combinations of one or more of the listed items may be used, and only one item in the list may be needed. For example, "at least one of: A, B, and C" includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A and B and C.

[0071] The description in the present application should not be read as implying that any particular element, step, or function is an essential or critical element that must be included in the claim scope. The scope of patented subject matter is defined only by the allowed claims. Moreover, none of the claims invokes 35 U.S.C. § 112(f) with respect to any of the appended claims or claim elements unless the exact words "means for" or "step for" are explicitly used in the particular claim, followed by a participle phrase identifying a function. Use of terms such as (but not limited to) "mechanism," "module," "device," "unit," "component," "element," "member," "apparatus," "machine," "system," "processor," or "controller" within a claim is understood and intended to refer to structures known to those skilled in the relevant art, as further modified or enhanced by the features of the claims themselves, and is not intended to invoke 35 U.S.C. § 112(f).

[0072] While this disclosure has described certain embodiments and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure, as defined by the following claims.

What is claimed is:

1. An apparatus comprising:

a capsule configured to be launched or carried towards an unmanned aerial vehicle (UAV); and

a directed energy device within or carried by the capsule, the directed energy device comprising a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV.

2. The apparatus of claim **1**, wherein:

the capsule is configured to be launched towards the UAV; and

the apparatus further comprises a loiter mechanism configured to maintain a position of the capsule or to slow a descent of the capsule after launch.

3. The apparatus of claim 2, wherein the loiter mechanism comprises at least one of: a rotor, an umbrella, and a parachute.

4. The apparatus of claim 1, wherein the first inductor and a capacitor form a resonant tank circuit.

5. The apparatus of claim 4, further comprising:

a second inductor through which a varying electrical current is able to flow and be mutually inducted into the resonant tank circuit.

6. The apparatus of claim 1, wherein:

the capsule is configured to be carried towards the UAV by a different UAV; and

the apparatus further comprises a tether coupling the capsule to the different UAV.

7. The apparatus of claim 6, wherein the directed energy device is configured to receive electrical power through the tether from the different UAV.

8. The apparatus of claim 1, further comprising:

a power supply configured to provide a supply voltage;

a power converter configured to receive the supply voltage and generate an output voltage different from the supply voltage; and

a power amplifier driver circuit configured to generate a drive signal for a transistor switch, wherein operation of the transistor switch causes generation of the inductive magnetic field based on the output voltage.

9. A system comprising:

a plurality of apparatuses each comprising:

a capsule configured to be launched towards an unmanned aerial vehicle (UAV); and

a directed energy device within or carried by the capsule, the directed energy device comprising a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV; and

a launcher configured to launch the capsules, the launcher comprising a tube.

10. The system of claim 9, wherein each apparatus further comprises a loiter mechanism configured to maintain a position of the capsule or to slow a descent of the capsule after launch.

11. The system of claim 10, wherein the loiter mechanism comprises at least one of: a rotor, an umbrella, and a parachute.

12. The system of claim 9, wherein, in each apparatus, the first inductor and a capacitor form a resonant tank circuit.

13. The system of claim 12, wherein each apparatus further comprises a second inductor through which a varying electrical current is able to flow and be mutually inducted into the resonant tank circuit.

14. The system of claim 9, wherein each apparatus further comprises:

a power supply configured to provide a supply voltage;

a power converter configured to receive the supply voltage and generate an output voltage different from the supply voltage; and

a power amplifier driver circuit configured to generate a drive signal for a transistor switch, wherein operation of the transistor switch causes generation of the inductive magnetic field based on the output voltage.

15. A system comprising:

a first unmanned aerial vehicle (UAV); and

one or more apparatuses each comprising:

a capsule configured to be carried by the first UAV towards a second UAV; and

a directed energy device within or carried by the capsule, the directed energy device comprising a first inductor configured to generate an inductive magnetic field that is able to inductively couple into one or more electronics of the second UAV in order to disable or destabilize the second UAV.

16. The system of claim 15, further comprising:

a tether coupling the one or more apparatuses to the first UAV.

17. The system of claim 16, wherein the directed energy device of each apparatus is configured to receive electrical power through the tether from the first UAV.

18. The system of claim 15, wherein, in each apparatus, the first inductor and a capacitor form a resonant tank circuit.

19. The system of claim 18, wherein each apparatus further comprises a second inductor through which a varying electrical current is able to flow and be mutually inducted into the resonant tank circuit.

20. A method comprising:

moving a directed energy device towards an unmanned aerial vehicle (UAV); and

generating an inductive magnetic field using a first inductor of the directed energy device, the inductive magnetic field able to inductively couple into one or more electronics of the UAV in order to disable or destabilize the UAV.

21. The method of claim 20, wherein moving the directed energy device towards the UAV comprises one of:

launching a capsule containing the directed energy device towards the UAV; and

carrying the capsule containing the directed energy device towards the UAV using a different UAV.

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